Energy Loss Prediction in a Compound Channel having Skewed Flood Plains using Artificial Neural Network

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Energy Loss Prediction in Compound Channel having Skewed Flood Plains using Artificial Neural Network

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Declaration of Originality

I hereby declare that this submission is entirely belongs to my own work done during the course of Master's Degree and I assure to the best of my knowledge that this work does not contain any piece of work that was taken directly from the work done by any researcher in the past nor it was taken from any article that was published in the past. This work was not submitted to any other university for the award of any other degree.

May 2016 MURAHARIRAO PREMCHAND
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Abstract

Energy loss in a compound channel is an essential requirement for determining any hydraulic parameters in a compound channel. Compound channels are generally classified as prismatic compound channels and non-prismatic compound channels. In prismatic compound channel the geometry of the channel remains same throughout the channel length and the energy loss takes place in a simple manner where as in the case of non-prismatic compound channels the geometry of the channel does not remains same throughout the channel length and the energy loss takes place in a complex phenomenon. In the present study non-prismatic compound channel with skewed flood plains is taken into consideration and the effect of skew angle and the skewed distance on the energy loss is studied. Artificial Neural Networks (ANN) is used as a tool for developing a relation among energy loss and different hydraulic parameters. Software named Computational Centre for Hydro-science and Engineering (CCHE-2D) is used to analyse the flow characteristics in a compound channel having skewed flood plains by simulating the Digital Elevation Model(DEM) of an artificial channel created using software named ARC-GIS. The flow parameters include depth averaged velocity and boundary shear stress values. Variation of depth averaged velocities of the compound channel was studies along five different sections along the skewed region of the channel. From the study it was clear that as the skew angle increases the velocity along the sections decreases. From ANN a model equation has developed using trained weights and biases and in order to find out the important parameter that is responsible for energy loss a technique called sensitivity analysis was carried out. From this sensitivity analysis skew angle (θ) was found to be the most important influencing parameter.

Key words: compound channels; skewed flood plains; energy loss; ANN; CCHE-2D; DEM; sensitivity analysis

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CHAPTER 1

INTRODUCTION

1.1 OVERVIEW

Energy loss in the compound channel takes place between main channel and the flood plain due the difference in height of flow between main channel and the flood plains. The flow in a non-prismatic channel is non-uniform flow due to which there will be development of turbulence and secondary currents at the interface of main channel and the flood plain. Due to these secondary flows there will be a huge loss in energy of main channel and thereby the resistance of the flow increases. In this condition there will an exchange of lateral momentum between the fast moving flow in main channel and the slow moving flood plains. Thus the prediction of energy loss in the compound channel becomes important in analysis of flow in a compound channel. Many research scholars studied different aspects which are responsible for energy loss in a compound channel which includes roughness coefficient, skew angle, divergent angle, convergent angle, momentum exchange mechanism between main channel and the flood plains, geometry of the channel.

1.2 OPEN CHANNEL FLOW

Flow in a channel will be considered as an open channel flow when the flow takes place in the channel under gravitational force to a greater extent and under atmospheric pressure. Generally flow in rivers and in artificial channels will be considered as an open channel flow. When we think about the artificial channels we come across different types of artificial channels. Artificial channels are of two types they are simple channels and compound channels. Simple artificial channels have only main channel without flood plains. The flow mechanism in these simple artificial channels is of simple in nature. Compound channels have flood plains along with the main channel. Flow mechanism in these compound channels is complex when compared to simple channels. These compound channels are again classified into prismatic compound channel and non-prismatic compound channel. In prismatic compound channel geometry of the channel remains same throughout the length of the channel where as in case of non-prismatic

Compound channel the geometry of the channel does not remain constant throughout the channel length.

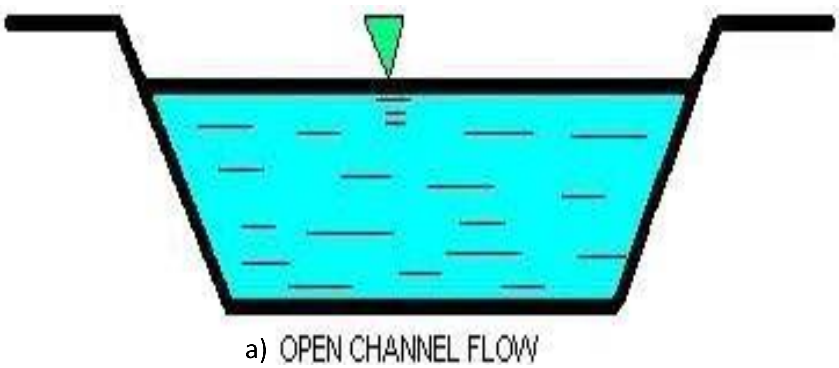


Fig 1.1 (a), (b) open channel flow

1.3 COMPOUND CHANNEL

Compound channel is a channel which consists of flood plains either on both sides of the main channel or any one side of the main channel. The flood plains are of different types some being skewed flood plain another being convergent and also divergent. Present work has been done on the compound channel which is having a skewed flood plain. The skewing can be of two types, one being the flood plains is skewed with respect to the main channel and the other being the main channel is skewed with respect to the floodplains. The compound channel which is having the flood plains skewed with respect to the main channel is used. In this work the data regarding the skewed channel was collected and the analysis was done regarding the parameters like boundary shear stress and the depth average velocity. The parameters like boundary shear stress and depth average velocity extracted from the data are compared with the parameters obtained from software CCHE 2D. Basic methodologies like Single Channel Method (SCM), Divided Channel Method (DCM) and ZASIM-1 (Zero Apparent Shear Interface Methods), ZASIM-2(Area Method) and the Coherence Method are used in order to find out whether the basic methods are applicable to the data extracted (Chlebek, 2009).

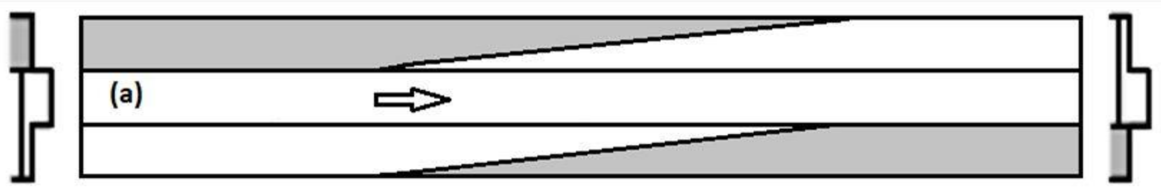


Fig 1.2.Diagram of skewed compound channel (Chelbek, 2010)

1.4 CCHE-2D:

Computational Centre for Hydro-science And Engineering (CCHE)-2D is a two dimensional software which was developed in order to perform hydrological analysis. Using this software one can able to find out the parameters like boundary shear stress values, depth average velocity contours. This software works on principle of

Computational Fluid Dynamics. Meshing concept comes in this software which is an easy technique to perform analysis. The different meshing methodologies included in this software are Chew's Refinement Algorithm and Zangh's Refinement Algorithm. Partial differential equations like elliptic system, parabolic system and hyperbolic system are used in generation of orthogonal meshes. This software consists of two parts one being the meshing part and the other being the Graphical User Interface (GUI). In meshing part the geometry file of the required channel is prepared, and then this geometry file is loaded in GUI and the initial and boundary conditions are to be given and the analysis is performed. The stretching function is widely used in the generation of algebraic mesh. In CCHE-2D mesh generator a more flexible and powerful two directional stretching function was used as follows:

$$S_j = \sum_{i=1}^{j-1}\left[\frac{2}{exp(\emptyset)+exp(-\emptyset)}\right]^E / \sum_{1}^{N-1}\left[\frac{2}{exp(\emptyset)+exp(-\emptyset)}\right]^E \quad (1.1)$$

$$\emptyset = \left[\frac{j-1}{N} - D\right] \times S \quad (1.2)$$

Where S_j = relative location, j = label of one point, N= total number of points along mesh lines, E= (-1, 0, 1) exponential parameter, D = ($0 \le D \le 1$) Deviation parameter, S= factor used for controlling the degree of stretching.

The governing equations which were solved in the CCHE-2D model are Continuity equation and the Momentum equations listed below

Continuity Equation

$$\frac{\partial Z}{\partial t} + \frac{\partial (hu)}{\partial x} + \frac{\partial (hv)}{\partial y} = 0 \quad (1.3)$$

Momentum Equations

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial Z}{\partial x} + \frac{1}{h}\left[\frac{\partial (h\tau_{xx})}{\partial x} + \frac{\partial (h\tau_{xy})}{\partial y}\right] - \frac{\tau_{bx}}{\rho h} + f_{cor}v \quad (1.4)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -g\frac{\partial Z}{\partial y} + \frac{1}{h}\left[\frac{\partial (h\tau_{yx})}{\partial x} + \frac{\partial (h\tau_{yy})}{\partial y}\right] - \frac{\tau_{by}}{\rho h} - f_{cor}u \quad (1.5)$$

Where u and v are the velocity components in x and y directions respectively and g is the acceleration due to gravity and Z is the water depth, ρ= density of water, h= local water depth, τ_{xx}, τ_{yx}, τ_{yy}, τ_{xy} are depth integrated Reynolds stress and τ_{bx} and τ_{by} are shear stress on the bed surface, f_{cor} is the Coriolis parameter.

1.5 ARTIFICIAL NEURAL NETWORK

Artificial Neural Network (ANN) is an arbitrary model which is used to develop a relation between the input and the output parameters. By using ANN one can find out the physical effects of input and output parameters. ANN works on the principle that firstly it trains the input data sets along with the target data sets and then it validates the some of the input data sets with target data sets. In this ANN one can use different training functions and different learning functions available in default. Based on the accuracy of the training and validating that particular training and learning function has to be adopted for the study. In the present study Feed-Forward Back Propagation training function was used. ANN model equation has developed by using the connection weights and the biases.

1.6 ORGANISATION OF THESIS

This thesis consists of 8 chapters which include chapter-1 Introduction, chapter-2 Literature review, chapter-3 basic methods for finding out discharge values in skewed compound channels, chapter-4 CCHE-2D simulation and procedure, chapter-5 observations from CCHE-2D, chapter-6 Energy loss calculation and ANN model equation, chapter-7 conclusions and scope of work, and References.

1. Chapter-1 consists of general introduction of the present study and different software used.
2. Chapter-2 consists of past research work done the study area.
3. Chapter-3 consists of basic methods which are used to find out discharge values in a skewed compound channel.
4. Chapter-4 consists of the details regarding CCHE-2D simulations and the procedure to be followed in simulating the CCHE-2D software.
5. Chapter-5 consists of results obtained from CCHE-2D simulations.
6. Chapter-6 consists of procedure for calculating energy loss and for developing ANN model equation.
7. Chapter-7 consists of conclusions of the present work and the scope of the future work to be carried out on the present study area.
8. Chapter-8 consists of references used for the present study.

CHAPTER 2

LITERATURE REVIEW

2.1 OVERVIEW

This chapter contains the ideas and the work done in past on the skewed compound channels. In 1977 itself investigation was started on flow parameters in a skewed compound channel by James and Brown. These investigations were carried out in many ways like finding out the effect of skew angles in flow parameters and many researchers concluded that as the skew angle increases the resistance to the flow also increases proportionally. Many experiments were carried out in laboratories worldwide in skewed compound channels for finding out the depth averaged velocities and the boundary shear stress distribution. Much work has done in finding out the different reasons and the different factors responsible for the energy loss in a compound channels. They have provided different factors responsible for energy loss in a compound channel which includes Roughness coefficient popularly known as Manning's *n* value, momentum exchange phenomenon between main channel and the flood plains. Many numerical and physical modelling was done on the present study area. Effect of geometry of the channel on the flow characteristics has also been studied in the past. Usage of different techniques like Artificial Neural Network (ANN) with proportionate to the open channel flow has also been studied in detail in the past.

2.2 PREVIOUS WORK DONE ON NON-PRISMATIC COMPOUND CHANNELS

James and Brown (1977) experimentally studied the stage-discharge relationship for a compound channel having wide flood plains. The effect of transfer mechanism between the flood plain and main channel was studied in detail. Their investigation revealed that the Manning's and Chezy's coefficient does not contribute much towards significance of parameters that contributes for the flow to take place. This investigation revealed a new method of treating flood plains and the main channel i.e. in this investigation they concluded that the flood plains and the main channel have to be considered separately for calculating hydraulic radius. Momentum exchange transfer between main channel and the flood plain studied in detail.

Knight and Demetriou (1983) experimentally studied the discharge characteristics, boundary shear stress and boundary shear force distribution in a compound channel having symmetric flood plains and rectangular main channel. Equations were given which gives shear force on the flood plains as percentage of total shear force with two dimensionless parameters. Experimental shear force values are used to derive equations for the lateral and vertical momentum transfer with in the cross section. It was inferred that apparent shear force on the vertical interface between main channel and flood plain is increasing for low relative depths and high flood plain widths. Flow division based on linear proportion of area was found to be inadequate due to the interaction of flow between the main channel and flood plains.

Knight et.al (**1984**) boundary shear stress and shear force distribution in a smooth rectangular channel was studied experimentally. Equations were developed which gives the percentage of total shear force that is carried by the walls of the rectangular channel in terms of breadth / depth ratio. Equations were developed which give the distribution of shear stress along mean wall, along the bed and along the centre line of the bed in terms of aspect ratio of the channel. Boundary shear stress distribution in an open channel and in closed conduits was compared for certain aspect ratios. Differences between the distribution of flow and the mean resistance coefficient in the secondary flow structure were discussed in detail.

Jasem (1990) explained the flow pattern in a skewed compound channels but here the main channel is slightly skewed with respect to the flood plains. The pattern of the depth averaged velocities and the lateral boundary shear stress values of the experiments conducted in the flumes are tabulated. Here it is inferred that for small skew angle of 5.84° the flow characteristics are much different when compared with the flow characteristics in a straight or simple channel. Energy loss for a certain slot in the channel bed in a limited version was also studied in this work. Experiment results were shown which reveals the deviation of flood plain stream lines, less lateral shear stress between main channel and the flood plain and the asymmetry of depth averaged velocity values due to flood plains skewed to main channel.

Elliott and Sellin (1990) confirmed the decrease in conveyance of the skewed compound channel when compared to the prismatic channels. The investigation on the flow had done in channels having skewed angles of 2.1º, 5.1ºand 9.2º. Experiment results had shown that the velocity distribution between main channel and the flood plains was distorted due to cross flow between main channel and the flood plains. They used momentum equation for analysing the flow for both the whole cross section and sub units in the compound channel. they made proposals for secondary circulation structure.

McGahey and Samuels (2003) described methods for calculating the physical flow process in a channel which was applicable to both flood plains and the river morphology. This study also includes the necessity of calibration coefficients which helps n analysing the physical flow process. A numerical solution was generated using finite element method. The pre requisite of the generated numerical solution was depth- integrated Reynolds Navier stokes equation. In this work importance was given to secondary flow energy loss mechanism and its effect on lateral velocity distribution. Depth- averaged velocity values are compared with the Flood channel Facility results.

Patra and Khatua (2005) enlightened that Manning’s coefficient n denotes the energy loss in the flow. The larger the value of n, the higher is the loss of energy within the flow. An investigation was done by the authors regarding energy loss with the difference of depths in straight and meandering compound channels. They have conducted much research on the effect of roughness coefficient on the energy loss in straight channels rather than meandering channels with and without flood plains. Energy loss in the compound channels was given in terms of Manning’s *n*, Chezy’s C and Darcy-Wesibach friction factor *f.*

Khatua (**2007)** explained different methods like DCM, SCM, ZASIM, area method, and the coherence method to predict the discharges. Many experiments were conducted for compound channels with straight and meandering channel. in this work it was explained regarding the energy loss in terms of Manning’s *n* and Chezy’s coefficient C. It was observed in this study that with the alteration of distribution shapes the shear stress along the main channel is getting decreased and the shear stress along the flood plain is increasing. An empirical equation which gives the percentage of boundary shear on the flood plain and information regarding the geometric parameters and sinuosity was discussed in detail.

S.K Das and P.K Basudhar (2008) explained the importance of Artificial Neural Network (ANN) in development of equation for predicting any output which is related with some input parameters. In this study residual friction angle was taken as an output parameter and with some input parameters a model equation was developed with trained ANN weights. A method called sensitivity analysis which will be useful to find out the important input parameters which are having more influence on the output parameter was explained in detail. Different methods like Garson's algorithm and Connection weight approach methods are explained in detail these methods are used in sensitivity analysis.

Chlebek(2009) Carried out the research by considering four different skew angles like 3.81°,2.1°,5.1°,9.2° and also analyse the flow in prismatic compound channels using Shiono Knight Method (SKM). Numerical modelling was done for the flow in simple channel with heterogeneous roughness i.e. with different roughness coefficient values in a single compound channel. Physical modelling has also performed for the flow in compound channel having skewed compound channel. The SKM method is capable of predicting the lateral distribution of depth-averaged velocity and boundary shear stress accurately. In this study guidance has been given to select the calibration coefficients namely friction coefficient, eddy viscosity and secondary flow respectively.

Chlebek et.al (**2010**) experimentally examined the flow phenomenon in different compound channels like compound channels having skewed flood plains and compound channels having diverging flood plains and compound channels having converging flood plains. From this study it was observed that the flow taking place from sub section to another sub section was different which results in the insignificant differences between the flood plains and the main channel. Three similarities in the flow behaviour were observed in this study based on the water level, velocity and bed shear values includes (1) there is an increase in head loss due to momentum transfer in the compound channel. (2) Velocity homogenous on the contracting flood plains of the compound channel. (3) There is an increase in the velocity gradient for expanding flood plains.

Proust et al. (2010) investigated energy losses in compound channel under non-uniform flow conditions using first law of thermo dynamics difference between the energy loss and head loss was studied. Head loss from one sub section to another sub section was different and the classical one dimensional hypothesis for calculating head loss was proved to be erroneous. A one dimensional couple momentum equation called "Independent Sub section method" ISM was used to resolve head loss. It was observed that flow parameters were influenced by the momentum flux which occurs due to the exchange of mass between main channel and the flood plain for al non prismatic geometries. Role of explicit model of mass conservation was also studied in detail.

P.K.Mohanty (2013) studied the flow characteristics in a compound channel having wide flood plains and the compound channel is meandering one. In this research work two different hydro dynamic tools are used in order to analyse the flow for both straight and meandering compound channels they are namely Conveyance Estimation System (CES) and Computational Centre for Hydro-Science Engineering (CCHE-2D). In this study all the important flow parameters are extracted from the simulations and these parameters are compared with the experimental data sets. Importance of study of energy coefficient and the momentum coefficient was described in detail in this study and models are developed with the extracted data and these models are compared with experimental data and data from the past research works.

B. Naik et al. (**2014**) explained the procedure of using ANN for the prediction of energy loss in non-prismatic compound channel and also explained about the influencing parameters of energy loss in channel. Procedure for calculating energy loss among different sections in a compound channel described in detail. Effectiveness of the ANN in predicting the energy loss of a compound channels having converging flood plains was discussed in detail. Selection of important hydraulic parameters which are responsible for energy loss in a compound channel was discussed in detail.

Das et al. (**2015**) explained about the flow characteristics and transfer mechanism in the skewed compound channels that it was a complex process. Momentum transfer reduces the total conveyance of the channel. Different methods were adopted in calculating the discharge values for skewed and converging compound channels. The various methods for calculating discharge values are as follows SCM and DCM methods. Various methods adopted have given best results when these results are compared with the experimental results. It was inferred that no method can be suitably adopted for converging compound channel at relatively higher depths.

Naik and Khatua(**2015**)explained the effect of geometry on the flow mechanism. Importance of modelling of the flow conditions in non-prismatic compound channels discussed in detail in this work. Stage discharge relations for converging compound channel have measured and presented in this work. It was inferred from the present work that the water surface profile is increasing with increase in relative depth for converging compound channel and the water surface profiles are decreasing along the converging length in case of sub critical flows. Water surface profiles in non-prismatic compound channels are influenced by the geometric and hydraulic parameters. Modelling which was done for converging compound channel was found to be in good relation with the experimental data.

2.3 CRITICAL REVIEW

From the literature review it was inferred that in the past much work has been done on the analysis of flow in prismatic compound channel but less work in non-prismatic compound channels like skewed, diverging, and converging compound channel. In a skewed compound channel the effect of skewed angle on the evaluation of flow parameters and the validation of the results with related standard software has not been effectively found. In such channel due to non-uniformity of flow the necessity of energy loss calculation had been felt important. There is no generalized model or a technique to predict the energy loss in a skewed compound channel.

2.4 OBJECTIVE OF STUDY

The main objective of the present research is to develop an equation which can be used to predict the energy loss in compound channel having skewed flood plains. In order to full fill the objective of the study data regarding the energy loss has to be acquired. For this purpose a software named Computational Centre for Hydro-science Engineering (CCHE-2D) is used to find out the depth averaged velocities in the compound channel. Digital Elevation Model (DEM) of the artificial skewed compound channel was prepared using software named ARC-GIS; this DEM file is an input file for CCHE-2D. Velocity values along different sections are extracted and these values are used in calculating energy loss values at different sections along the channel. These energy loss values are used in ANN for developing an equation for predicting energy loss.

CHAPTER 3

BASIC METHODS AND DATA COLLECTION

3.1 OVERVIEW

There are different methods adopted in this study in order to study the flow geometry. Initially the basic methods are applied in discharge prediction in order to verify the effect of skewing in the compound channel. The main aim of this attempt is to verify whether basic methods of discharge prediction are suitable for skewed compound channel or not. These methods include SCM method, DCM method, ZASIM method, ZASIM-2 method, Coherence method. Discharge values were calculated using the methods and these discharge values are compared with experimental discharge values for their respective effective depth values. The predicted discharge values are very close to the experimental discharge values. Hence these basic methods can be used for skewed compound channel. This section gives information about the data collection.

3.2 SCM METHOD: In this single channel method the entire compound channel is taken as single channel and the discharge values are calculated using Manning's equation. The roughness value is taken equal for both main channel and the flood plains.

$$Q = \frac{AR^{\frac{2}{3}}\sqrt{S}}{n} \tag{3.1}$$

A= Area of the compound channel, R= Hydraulic mean radius;

S= longitudinal slope of the main channel, *n*= Manning's roughness value.

3.3 DCM METHOD: In this method the main channel and the flood plains are treated as separate units and the discharge values are calculated using the same Manning's equation. In this method also same value of Manning's "*n*" is taken for both main channel and the flood plain. The difference in this method is that discharge values are calculated separately for main channel and flood plains and at last both the values are added in order to get total discharge of the compound channel.

$$Q_f = \frac{A_f R_f^{\frac{2}{3}}\sqrt{S}}{n} \tag{3.2}$$

Q_f = discharge value of the flood plain, A_f= Area of the flood plain, R_f= Hydraulic mean radius of the flood plain; S= longitudinal slope of the main channel, Q_m = Discharge value of the main channel; A_m = Area of the main channel, R_m = Hydraulic mean radius of the main channel, S= longitudinal slope of the channel.

$$Q_{total} = Q_m + Q_f \tag{3.4}$$

3.4 ZASIM-1(Zero Apparent Shear Stress Method):

This method also comes under Divided channel method in which the main channel and the flood plains are divided by an inclined interface starting from the junction of the main channel and the flood plain to the middle of the main channel on the water depth over the flood plain. In this method the shear stress along the inclined interface is assumed to be zero. The discharge is calculated same as that of DCM method

$$Q_f = \frac{A_f R_f^{\frac{2}{3}} \sqrt{S}}{n} \tag{3.5}$$

$$Q_m = \frac{A_m R_m^{\frac{2}{3}} \sqrt{S}}{n} \tag{3.6}$$

Q_f = discharge value of the flood plain; A_f = Area of the flood plain, R_f = Hydraulic mean radius of the flood plain, S= longitudinal slope of the main channel, Q_m = Discharge value of the main channel, A_m = Area of the main channel, R_m = Hydraulic mean radius of the main channel

$$Q_{total} = Q_m + Q_f \tag{3.7}$$

3.5 ZASIM-2 (AREA METHOD (AM)):

This method also comes under divided channel method but there is a slight difference in this method that is here the shear stress is assumed to be zero along a curved surface starting from the junction of the main channel and the flood plains. The area of this curved surface is calculated by using empirical equation given by Prinos – Townsend. This area calculated should be deducted from main channel area and should be added to the flood plains area which gives the modified area of main channel and the flood plains. These areas are used in calculating discharge values for main channel and the flood plains.

$$\Delta A = T_r \, d^2 \tag{3.8}$$

$$T_r = \frac{\partial v^{0.92} \, \beta^{-1.129} \alpha^{-0.514}}{11.213 dS} \tag{3.9}$$

α = width ratio of compound channel, d =depth of water over flood plain,B = depth ratio of the compound channel, S = longitudinal slope of the compound channel, ∂v = difference in mean velocities of main channel and flood plains; ΔA = the area of the curves interface, Tr = relative apparent shear stress.

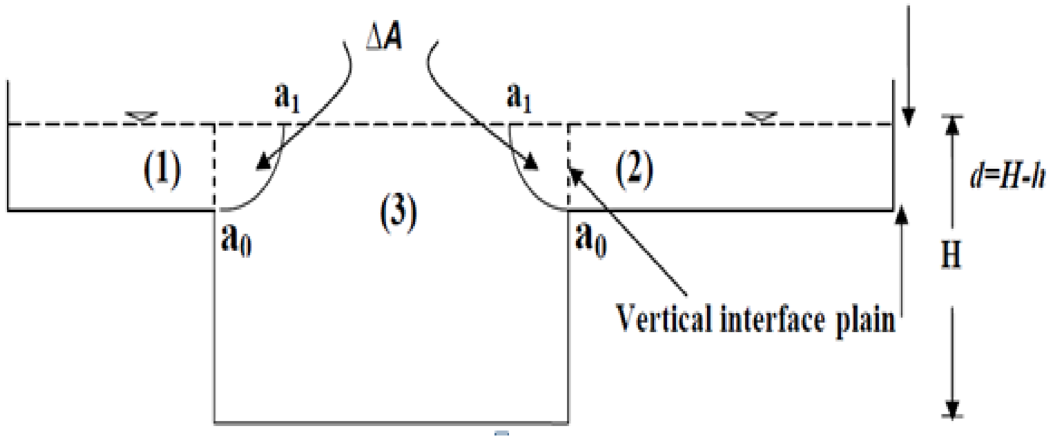


Fig 3.1.Division of compound channel in AREA Method (Khatua2007)

3.6 THE CHORENCE METHOD (COH):
Coherence is defined as the ratio of the basic conveyance calculated by treating the channel as a single unit with perimeter weighing of the friction factor to that calculated by summing the basic conveyances of the separate zones. This coherence method is developed by Ackers (1992 and 1993).The equation for finding out Coherence (COH) is as follows:

$$COH = \frac{\sum_{i=1}^{n} A_i \sqrt{\frac{\sum_{i=1}^{n} A_i}{\sum_{i=1}^{n} f_i \times P_i}}}{\sum_{i=1}^{n} A_i \sqrt{\frac{A_i}{f_i \times P_i}}} \tag{3.10}$$

Where i denotes the no. of flow zones; A_i = sub area, P_i= wetted perimeter of each sub area, f= Darcy’s Wesibach friction factor

The equation is further simplified as follow

$$COH = \frac{(1+A')\sqrt{\frac{(1+A')}{(1+P\prime \times f\prime)}}}{(1+A')\sqrt{\frac{A\prime}{(P' \times f')}}} \tag{3.11}$$

Where $A' = \frac{N_f \times A_{fp}}{A_{mc}}$, $P' = \frac{N_f \times P_{fp}}{P_{mc}}$, N_f= no. Of flood plains, A_{fp}= area of flood plains, A_{mc}= area of main channel, P_{fp} = wetted perimeter of flood plain, P_{mc}= wetted perimeter of the main channel; For compound channel having smooth boundary f' is taken as unity i.e. f'=1.0. Value of coherence is always less than unity hence discharge adjustment factor is necessary in order to correct the individual discharge values of the sub areas.
The discharge adjustment factor is calculated by using empirical formula as follows

$$DISADF = (0.6431 \times COH) + 0.3611 \quad (3.12)$$

$$Q_{basic} = DISADF \times \sum_{i=1}^{n} Q_i \quad (3.13)$$

Where DISADF = discharge adjustment factor, COH= coherence, Q_{basic}= calculated discharge,
Q_i = discharge in sub area.

3.7 DATA COLLECTION

For the present analysis the data was collected from the , The University of Birmingham flume which has a total length of 18 m, a depth of 400 mm and a 398 mm wide main channel which is 50 mm deep Fig. 3.2(a). There are two floodplains which are each 398 mm wide. The flume has a bed slope of 0.002003 and Manning's *n* value taken as 0.0098. In the non-prismatic sections, the channel had a total of 6 measuring sections; one at the start of the transition, three intermediate sections, one at the end and one 1m downstream of the end of the transition (Fig 3(b)).The actual relative depths corresponding to the discharges listed in Table 1 were fixed to *Dr* = 0.205, 0.313, 0.415 and 0.514.

Fig 3.2(a).University of Birmingham experimental flume with skewed geometry
(Birmingham university flume, 1990)

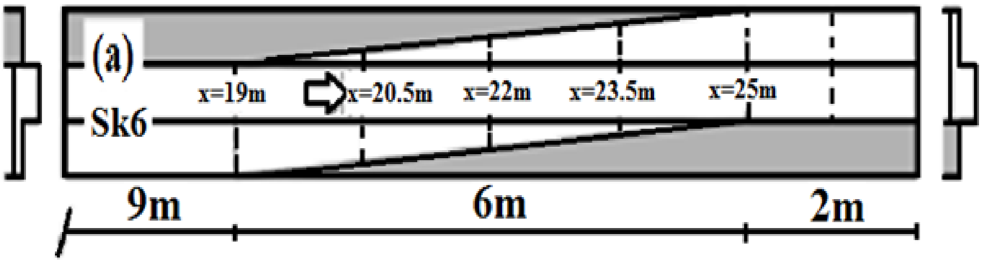


Fig 3.2(b) 6m skewed compound channel having 5 test sections (x=19m, x=20.5m, x=22m, x=23.5m, x=25m)

3.8 OBESERVATIONS:

Discharge values are calculated for different relative depths using SCM, DCM, ZASIM-1, ZASIM-2 (AREA METHOD) AND THE COHERENCE methods and these calculated values are compared with the experiment discharge values. Error analysis was performed in order to find out the methods among all the methods which are effectively close to the experimental discharge values.

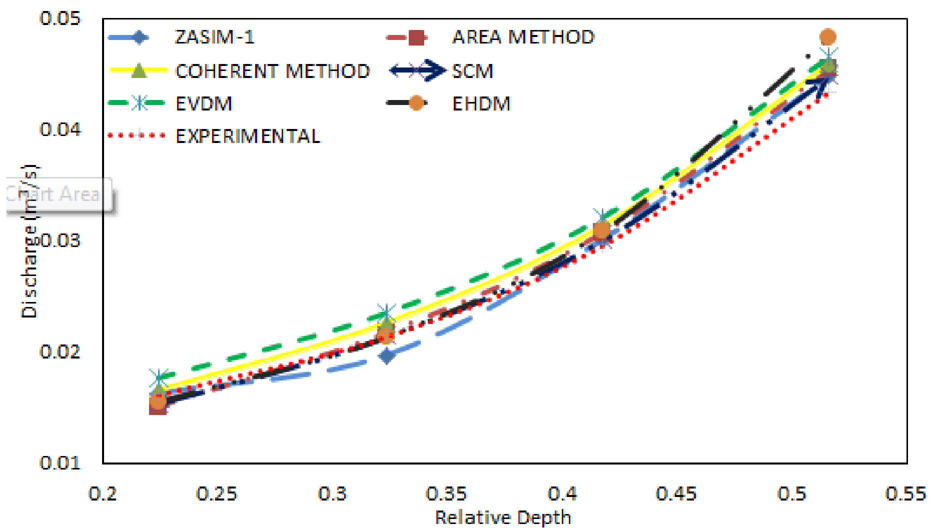


Fig 3.3 Comparison of discharge values of different methods for relative depths of 0.22, 0.32, 0.42 and 0.52

Table 3.1. Error analysis for the skewed compound channel

Relative depth(D_r)	Percentage error (%)					
	SCM	EVDM	EHDM	ZASIM	AM	COH
0.22	5.44	8.9	4.31	0.42	6.93	2.18
0.32	0.11	9.75	0.46	7.96	1.49	5.51
0.42	1.79	8.37	4.05	1.74	3.71	5.77
0.52	3.33	7.18	11.2	3.27	4.64	5.69

From Table 3.1, it is clear that all the methods are relatively closer to the experimental discharge value. From this analysis it is clear that all the methods can be used for discharge calculations in a compound channels having skewed flood plains. But for different relative depths most suitable methods summarized as follows: for relative depth of 0.22, 0.42 and 0.52, ZASIM is very effective whereas for 0.32, EHDM gives good agreement with the experimental discharge value.

CHAPTER 4

CCHE-2D SIMULATION PROCEDURE

4.1 OVERVIEW

This chapter deals with the software named Computational Centre for Hydro-science Engineering (CCHE-2D) which was used in the present study for analyzing the flow parameters in a compound channel having skewed flood plains. This chapter deals with what are the input files to this software and what was the procedure followed in creating required input files and procedure for simulations in CCHE-2D. This software requires input file as Digital Elevation Model of laboratory flume in ASCI format. This required ASCI format of the laboratory flume is done using software called ARC-GIS. Various boundary and initial conditions are assigned and the simulation process was carried out. Required velocity values and the boundary shear stress values are extracted from the simulation results using “Probe” window

4.2 CCHE-2D:

Centre for Computational Hydro-science Engineering software is used to analyze the flow parameters like depth averaged velocity and the average boundary shear stress. This software requires input files in the format as follows

- Digital Elevation Model(ASCII)
- Topographical model
- Shape file (AUTO CAD OR ANSYS)

First one is opted for the present study that is a Digital Elevation Model is created using ARC-GIS software for the artificial compound skewed channel. Data required to create DEM is elevation values trough out the length of the compound channel and the approximate latitude and longitude values throughout the length of the channel and these latitude and longitude values are taken from Google map and the elevation data is prepared for the channel by taking the bed of the main channel as a reference level and the elevation values are calculated along the length of the channel with the help of longitudinal slope. The required input format of the CCHE-2D is ASCII file is created in the ARC-GIS using the prepared latitude and longitude values and the elevation values. Digital Elevation model for the artificial channel of length 18 meters and width of 1.2 meters having flood plains skewed at an angle of 3.81° with respect to the top ridge of the main channel is prepared using Arc GIS. CCHE-2D requires trial and error process in assigning initial and boundary conditions like initial bed elevation and initial water surface elevation. The channel will not have skewed flood plains until 9 meters of the length from the starting and the skewing of the flood plains starts from 9m with an angle of 3.81° to a length of 6m, there ends the skewed flood plains the remaining part of the channel has normal flood plains. Initially the skewed flood plains are not provided in order to create uniform flow conditions. The Digital Elevation Model of the above channel is as follow:

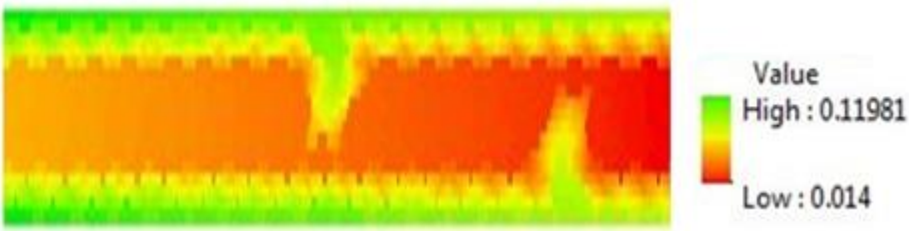


Fig 4.1.DEM of channel in ARC- GIS

4.3 PROCEDURE FOR SIMULATION

Step 1: First thing to do in order to simulate the results in CCHE-2D is to load the Digital Elevation Model in the ASCII format. A pop up window appears in which the meshing details can be given like number of rows and number of columns of the mesh so that the meshing takes place directly. Meshing details include the no.of "i "values and no.of "j "values. The maximum no.of i lines cannot exceed the no.of columns in the DEM file and the maximum no.of j lines should not be less than no.of rows in the DEM file. Meshing can also be done manually but it takes some time and in meshing manually one has to take care of deviation from orthognality which should be maintained less. Hence it is better to do meshing directly.

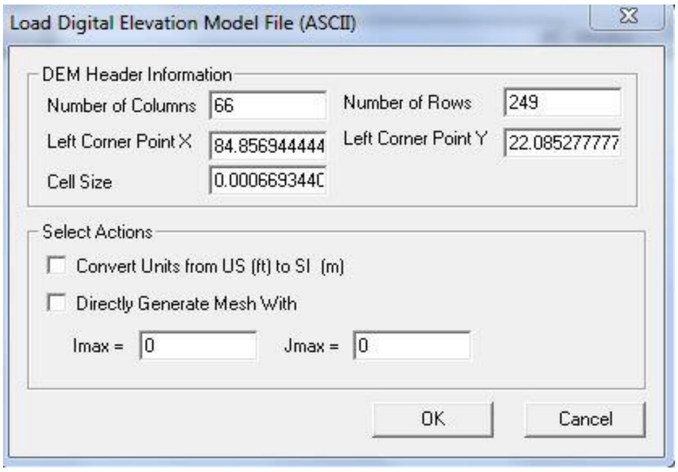


Fig 4.2.Pop up window for loading DEM file.

Step 2: After meshing has done save the file as geometry file which is the input file for simulation process in CCHE-GUI.

Step 3: Open the geometry file which was already saved. This geometry file has to be assigned with initial, boundary conditions and the flow parameters.

Step 4: Boundary conditions are assigned to the geometry file using set boundary conditions option in the user interface. These boundary conditions include discharge value at inlet and the water surface at outlet. Nodes are added at inlet ant outlet of the geometry file. A pop up window appears where the boundary condition values can be given.

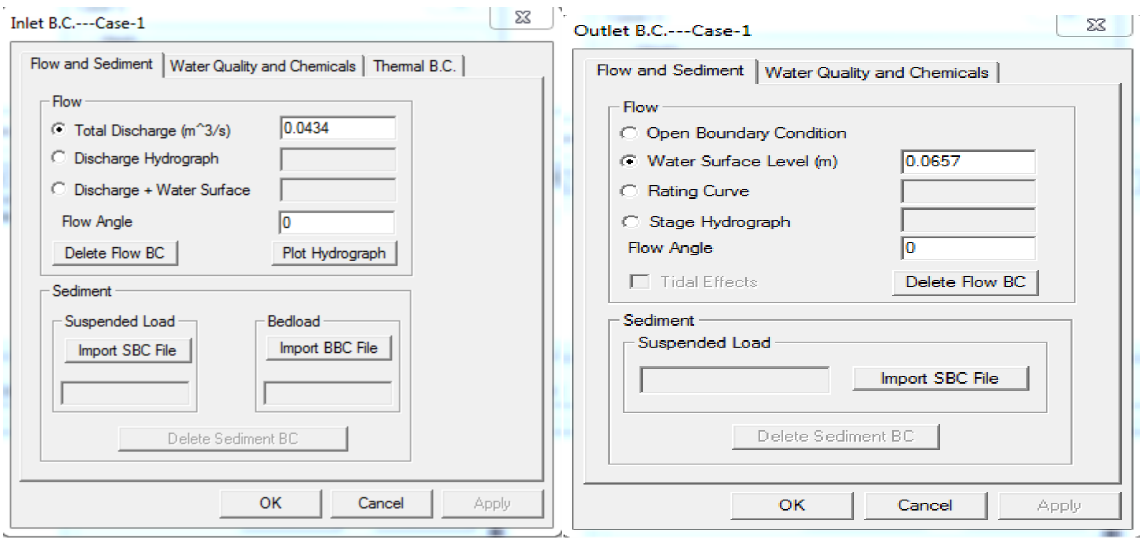


Fig 4.3 (a), (b) pop windows for assigning boundary conditions

Step 5: After assigning boundary conditions initial conditions has to be assigned to the geometry file. These initial conditions include initial water surface, initial bed elevation, roughness value, errodibility value, maximum deposition thickness. Similar to the boundary conditions a pop up window appears for each initial condition where the value can be given. These initial conditions can be given to either whole domain or for a particular region of requirement.

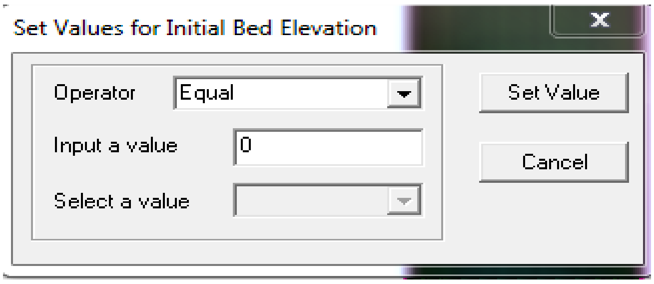


Fig 4.4 pop up window for assigning initial conditions

Step 6: After assigning initial conditions the flow parameters has to be given to the geometry file. These flow parameters include time of simulation, time step, time for intermediate flow file, type of model and many others. Since the flow is non-uniform the type of model used is parabolic eddy viscosity model should be used. This is a trial and error process in which the time step has to be changed until the simulation goes correctly. Care should be taken that the time step should not be much bigger.

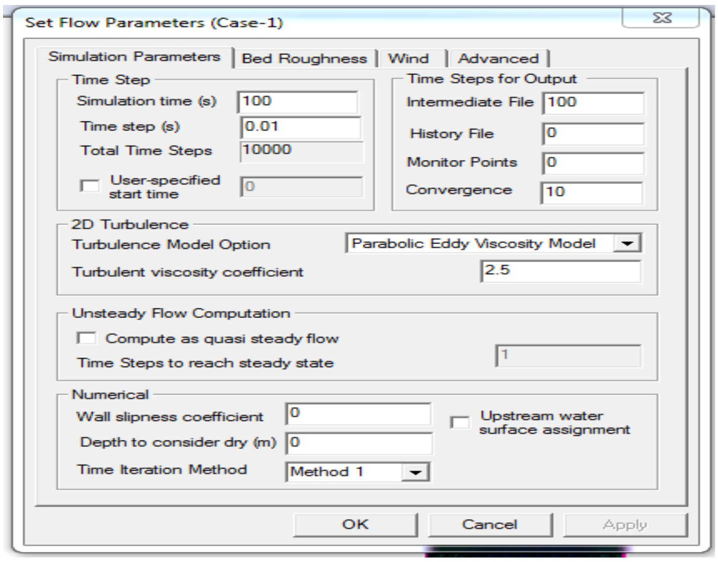


Fig 4.5.pop up window for assigning flow parameters

Step 7: After assigning the flow parameters simulation has to be done by using run simulation option in the user interface. If all the initial, boundary and flow parameters are suitable for the simulation to execute there will be no errors shown in the execution window but if the conditions are not suitable there will be some errors shown on the window based on the errors the conditions should be changed and again the simulation process should be started until the execution is error free. If the execution goes correctly the final flow file will be displayed from where the results can be extracted.

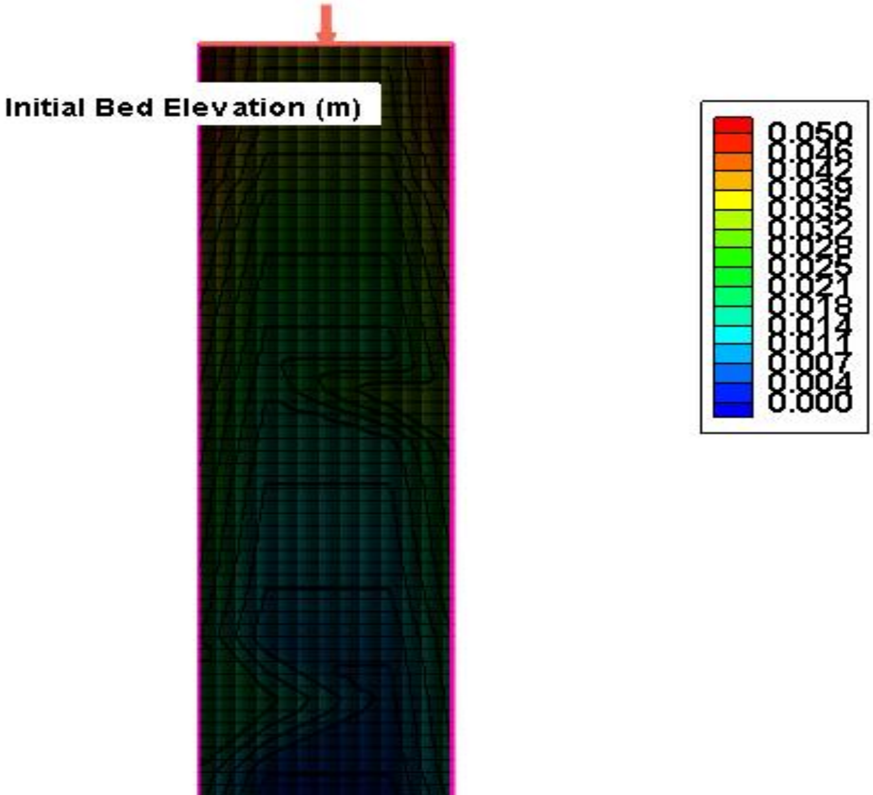


Fig 4.6, simulated geometry file

Step 8: Since the simulation went successful the results from the flow final file has to be extracted. For this purpose there is an option called “Probe” where the values can be extracted at required i and j points. The results includes depth averaged velocity, boundary shear stress, Froude number, water surface, water depth, bed elevation etc.

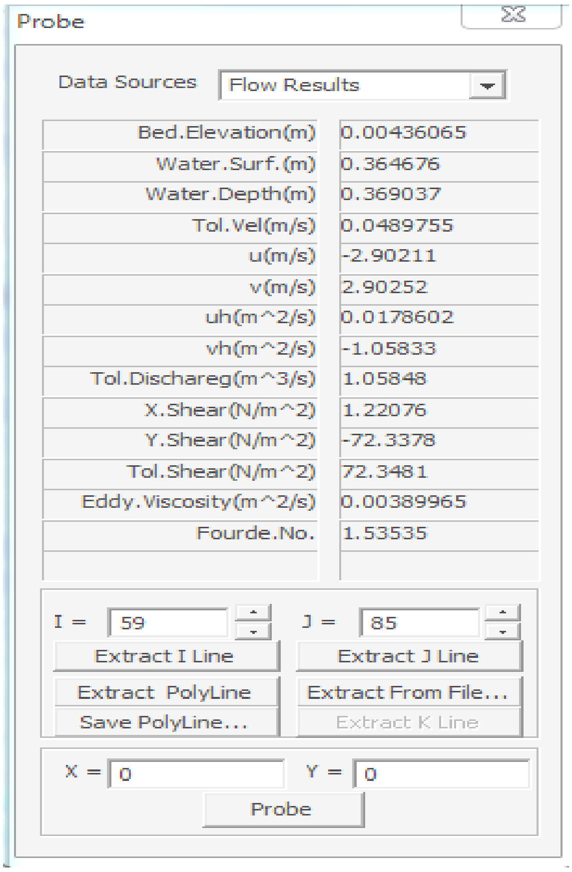


Fig 4.7, probe window

CHAPTER 5

CCHE-2D SIMULATION RESULTS AND OBSERVATIONS

5.1 OVERVIEW

This chapter consists of results from simulations of CCHE-2D software. Digital Elevation Model (DEM) for an artificial channel having skewed flood plains was prepared for different skew angles like 2.1°, 3.81°, 5.1° and 9.2° respectively. From the results it was observed that the CCHE-2D software is over estimating the velocity and boundary shear stress values. This was observed when the results are compared with experimental results. Boundary shear stress values from the simulation results are varying in greater extent with the experimental results. Hence the boundary shear stress values are not taken into consideration in the present study. Velocity values from the simulation results are also varying in greater extent with the experimental values but when the values are normalised they are following the same trend as that of the experimental values. Variations of velocity values along the different sections in the skewed region are studied and it was observed that velocity decreases along the skew length of the channel.

5.2 RESULTS FROM CCHE-2D

DEM files which are prepared for different skew angles like 2.1°, 3.81°, 5.1°, and 9.2° are simulated in CCHE-2D and all the simulations went successful. Results from the simulations for different skew angles like 3.81°, 2.1° and 5.1° and 9.2° are collected and tabulated. The results from the simulation of DEM file having skew angle of 3.81° is compared with the experimental results available for the artificial channel having skew angle of 3.81°, and these results are also compared with the results from simulation of DEM file having skew angle 2.1°, 5.1° and 9.2° in order to find the effect of skew angle in the analysis of flow in skewed compound channels using software CCHE-2D. The only difference which follows in artificial channels having different skew angles is that the length of the skewed portion changes with respect to the skew angle. Results from the simulations are extracted for three angles of 3.81°, 2.1°, 5.1° and 9.2º. Boundary shear stress and depth averaged velocity values are extracted from the simulation results and these values are used to compare with experimental data sets.

5.3 COMPARISON OF CCHE-2D RESULTS

The results which are extracted from the simulations are compared with the experimental data set. The results include the values of boundary shear stress and depth averaged velocity values for 2.1°, 3.81°, 5.1° and 9.2° skew angles. These values are extracted for different discharge values and along different sections in the skewed portion. In case of boundary shear stress the simulation results and the experimental results are varying in wide range because of the unavailability of the governing equation for calculation of boundary shear stress in the software CCHE-2D which is the problem faced with many simulation programmes. But the depth averaged velocities from the simulations are somewhat satisfactory even if the values are higher than experimental data sets.

5.4 OBSERVATIONS

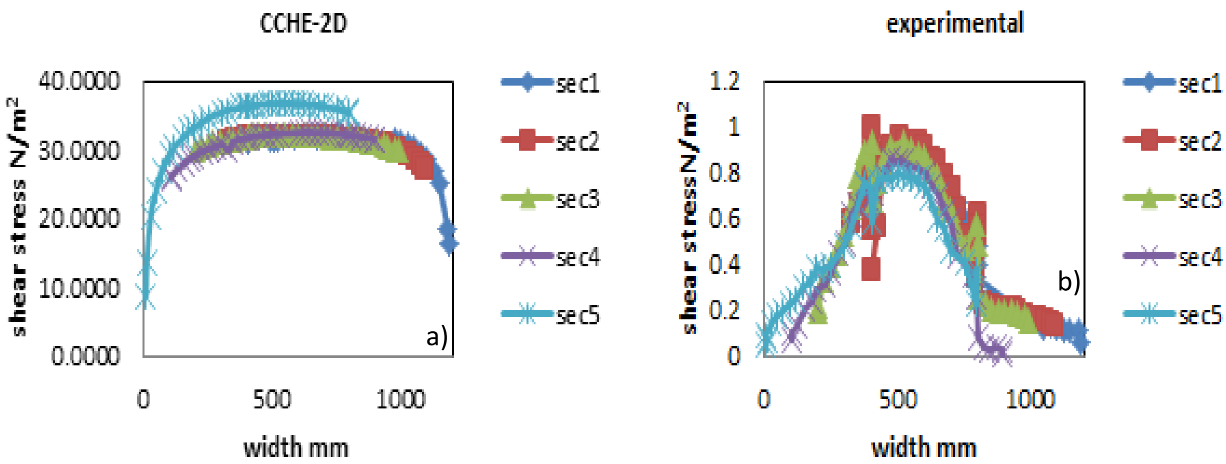


Fig 5.1 (a), (b) comparison of boundary shear stress values between CCHE-2D and Experimental data for 3.81° and Q=16.2 L/s

From Fig 5.1 (a) and (b) it is clear that the results from the CCHE-2D are following the same pattern as that of the experimental data but the variation of boundary shear stress values along the floodplains and the main channel in CCHE-2D is very less when compared to experimental data and also the values from software are over estimated when compared with experimental data. Hence CCHE- 2D software is not efficient in estimating the boundary shear stress values for compound channels having skewed floodplains. This is due to unavailability of governing equation for calculating boundary shear stress which was commonly seen in the simulation programmes. Boundary shear stress values for other discharge values like 21.4L/s,29.6L/s,43.4L/s are also verified and they are following the same trend as that of the above mentioned discharge so they are not mentioned in detail.

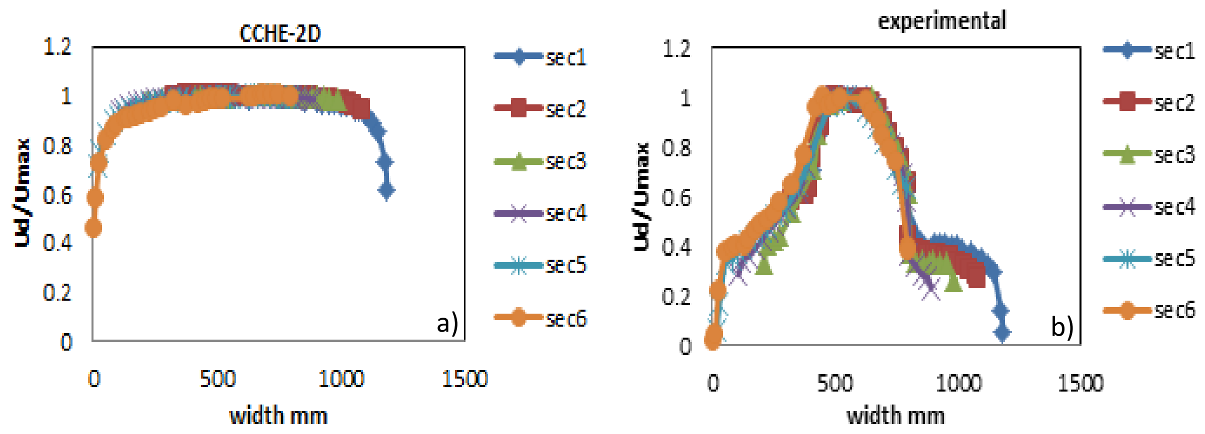


Fig 5.2 (a), (b) comparison of normalised depth averaged velocities for Q=16.2L/s

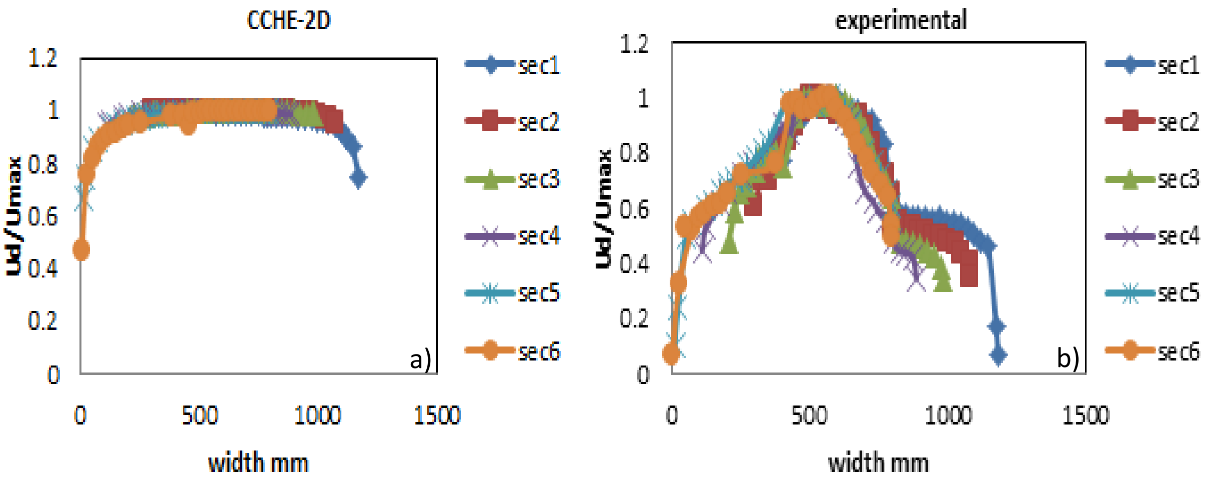


Fig 5.3 (a), (b) comparison of normalised depth averaged velocity for Q=21.4L/s

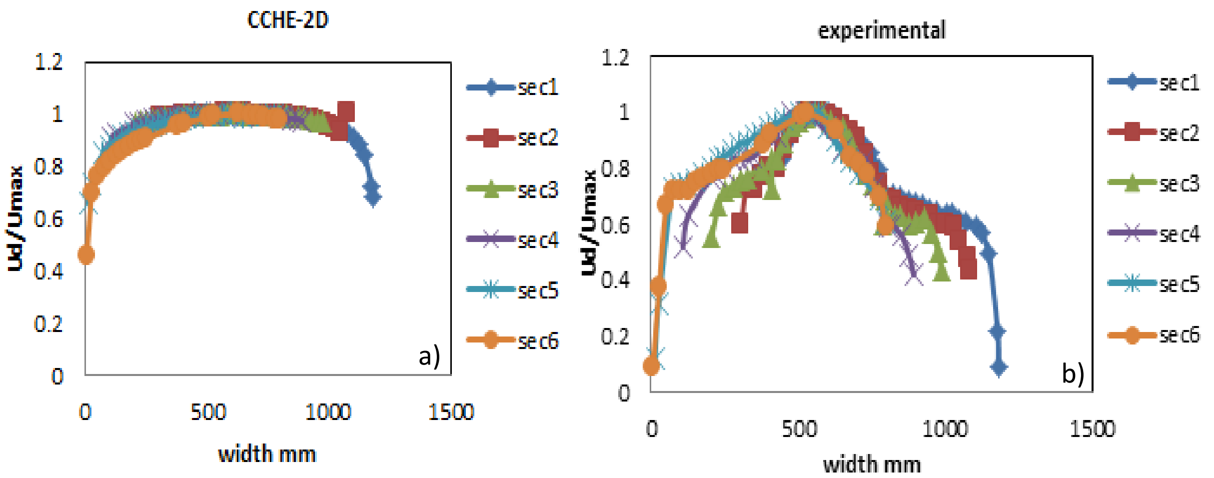


Fig 5.4 (a), (b) comparison of normalised depth averaged velocity for Q=29.6L/s

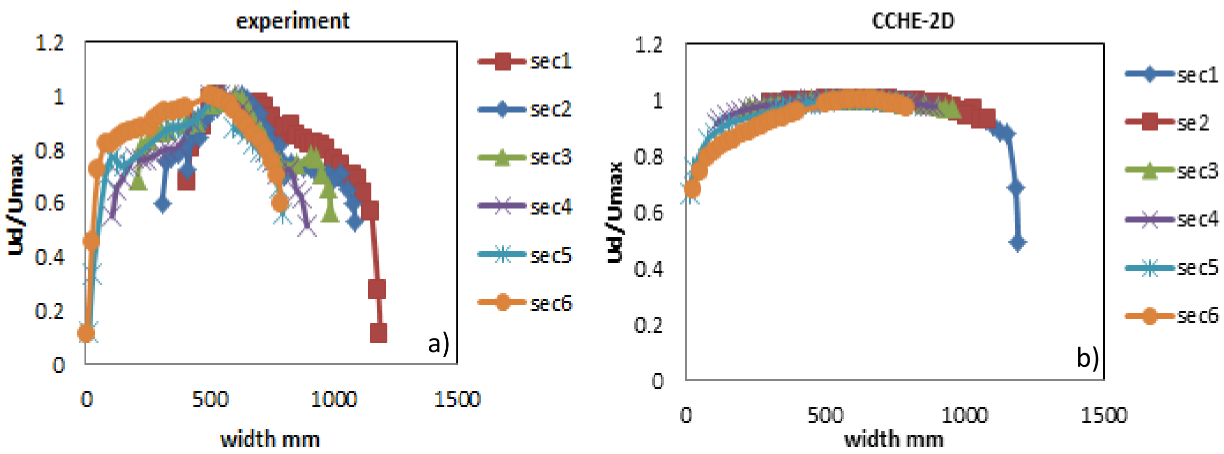


Fig 5.5 (a), (b) comparison of normalised depth averaged velocity for Q=43.4L/s

From the above figures it is clear that the velocity values extracted from the simulation results of CCHE-2D almost follows similar trend as that of the experimental data, but the values from CCHE-2D are bit higher in magnitude when compared with experimental data sets. The variation of velocity values along the flood plains and main channel is less in CCHE-2D simulations.

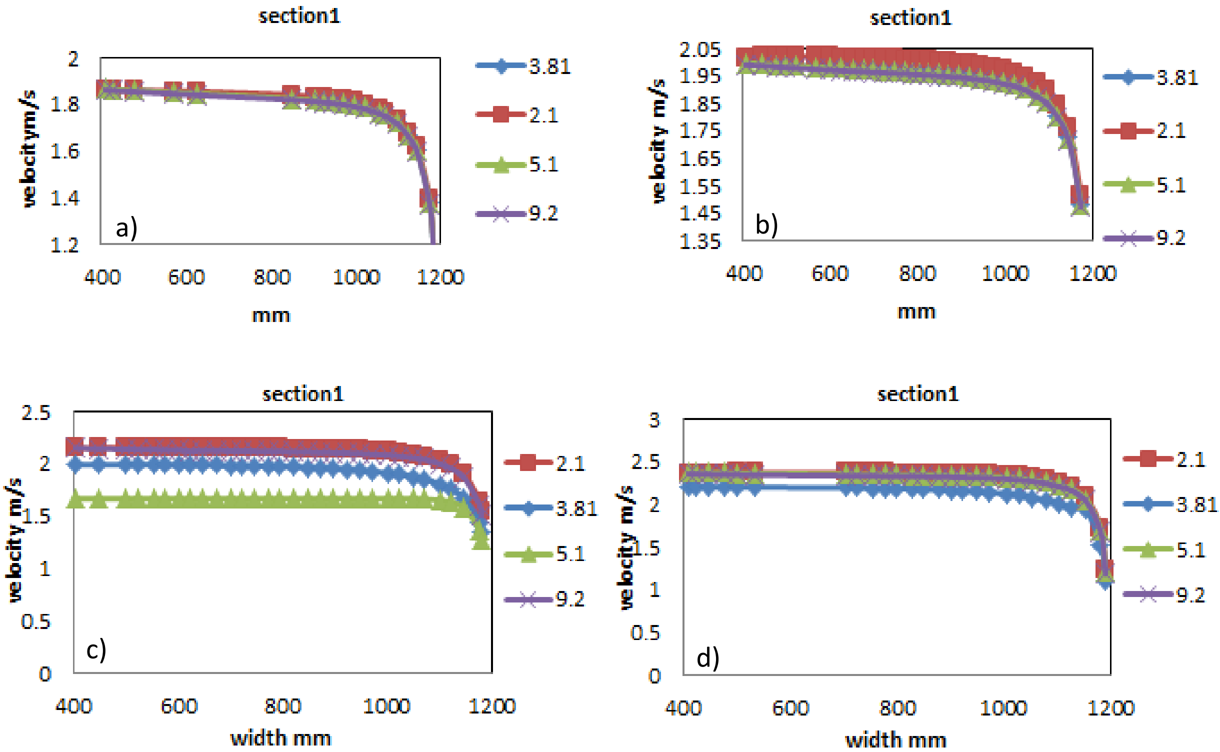


Fig 5.6 (a), (b), (c), (d) comparison of depth averaged velocity in section1 of the skewed portion with Q=16.2L/s,21.4L/s,29.6L/s and 43.4L/s respectively

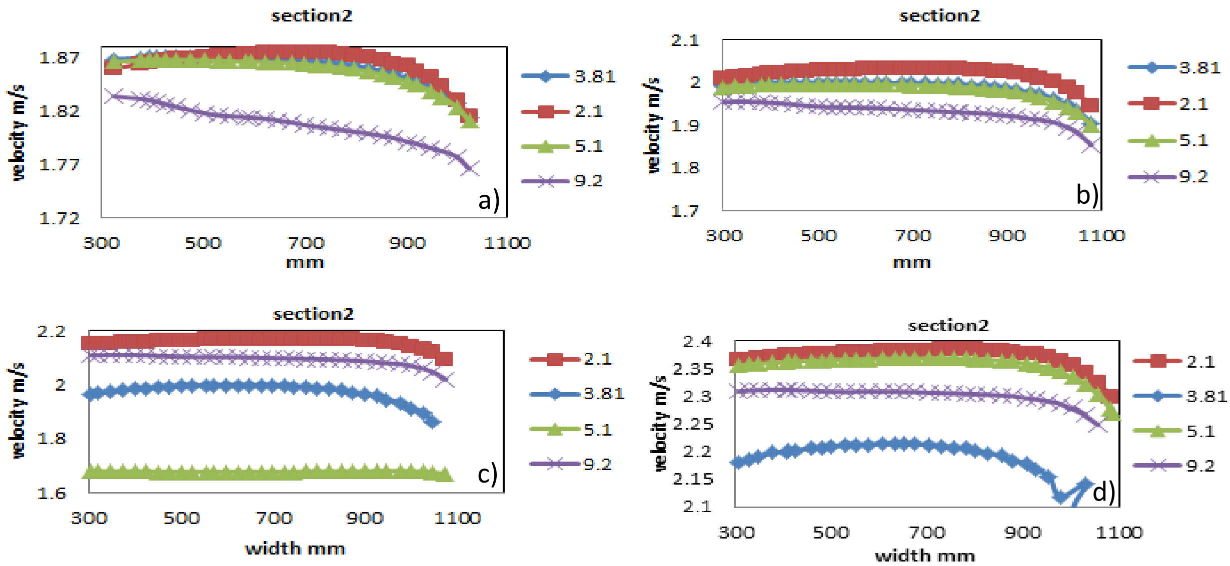


Fig 5.7 (a), (b), (c), (d) comparison of depth averaged velocity in section2 of the skewed portion with Q=16.2L/s,21.4L/s,29.6L/s,43.4L/s respectively

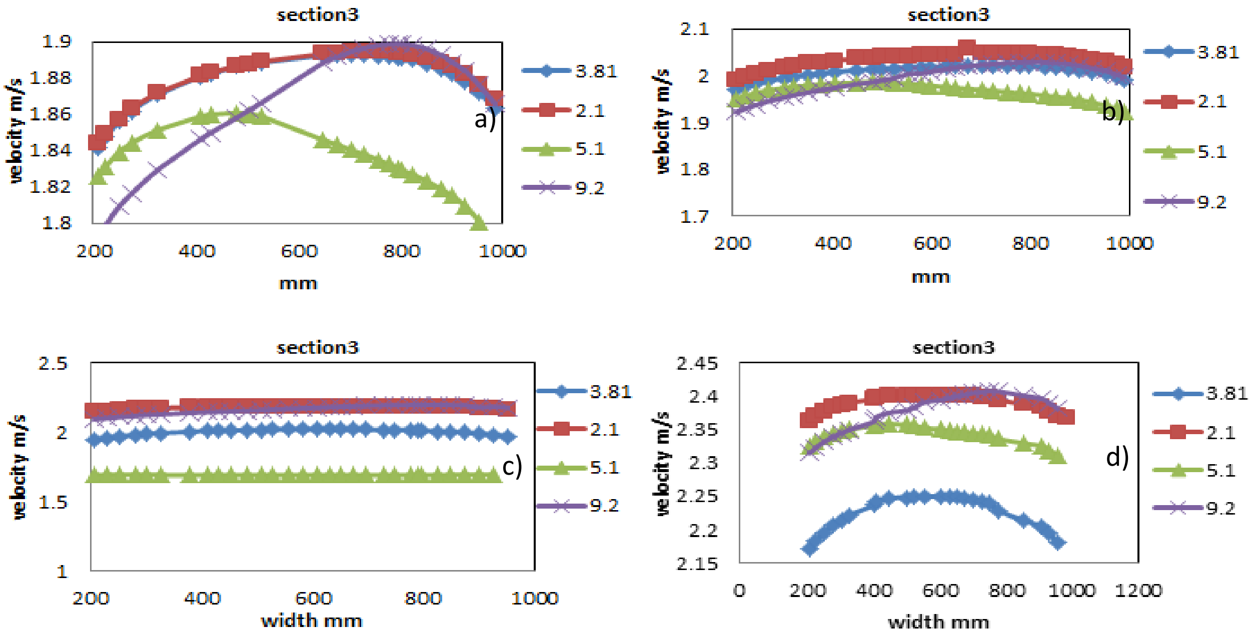


Fig 5.8 (a), (b), (c), (d) comparison of depth averaged velocity in section3 of the skewed portion with Q=16.2L/s,21.4L/s,29.6L/s,43.4L/s respectively

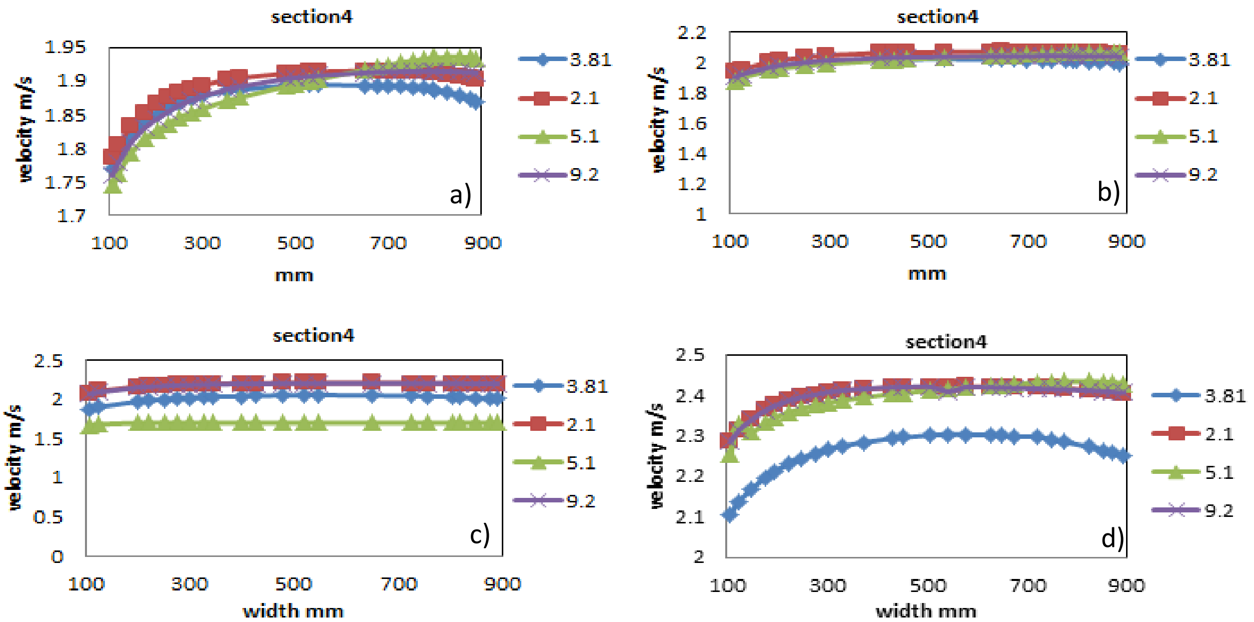


Fig 5.9 (a), (b), (c), (d) comparison of depth averaged velocity in section4 of the skewed portion with Q=16.2L/s,21.4L/s,29.6L/s and 43.4L/s respectively

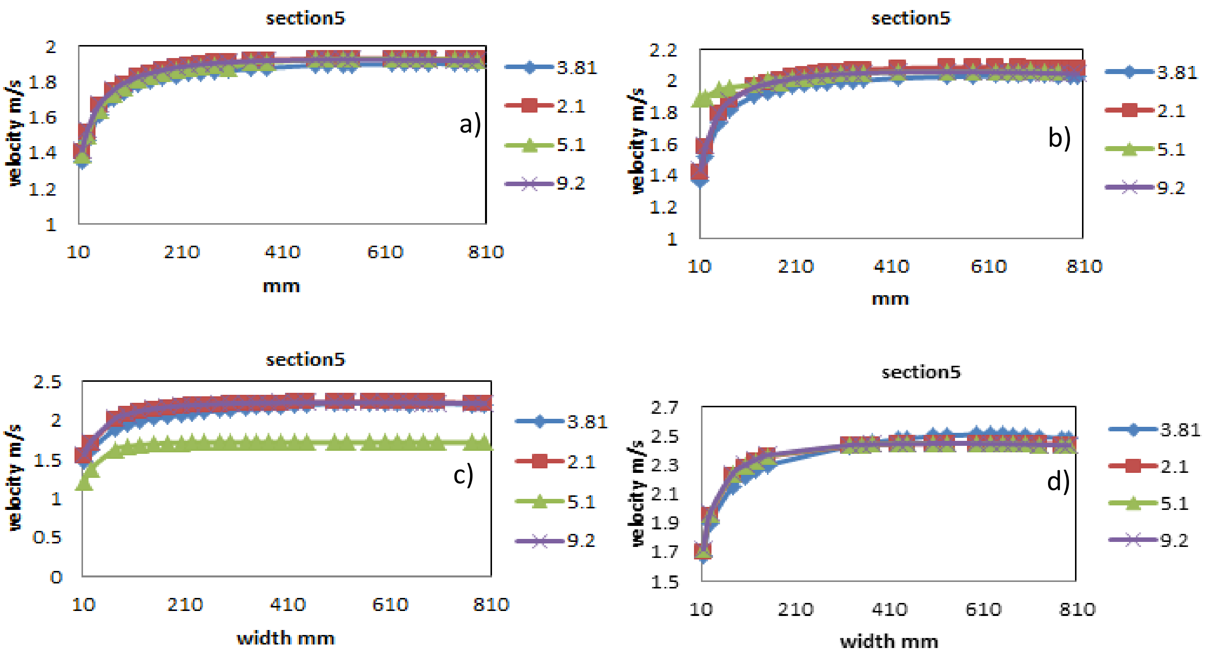


Fig 5.10 (a), (b), (c), (d) comparison of depth averaged velocity for section5 of the skewed portion with Q=16.2L/s,21.4L/s,29.6L/s,43.4L/s respectively

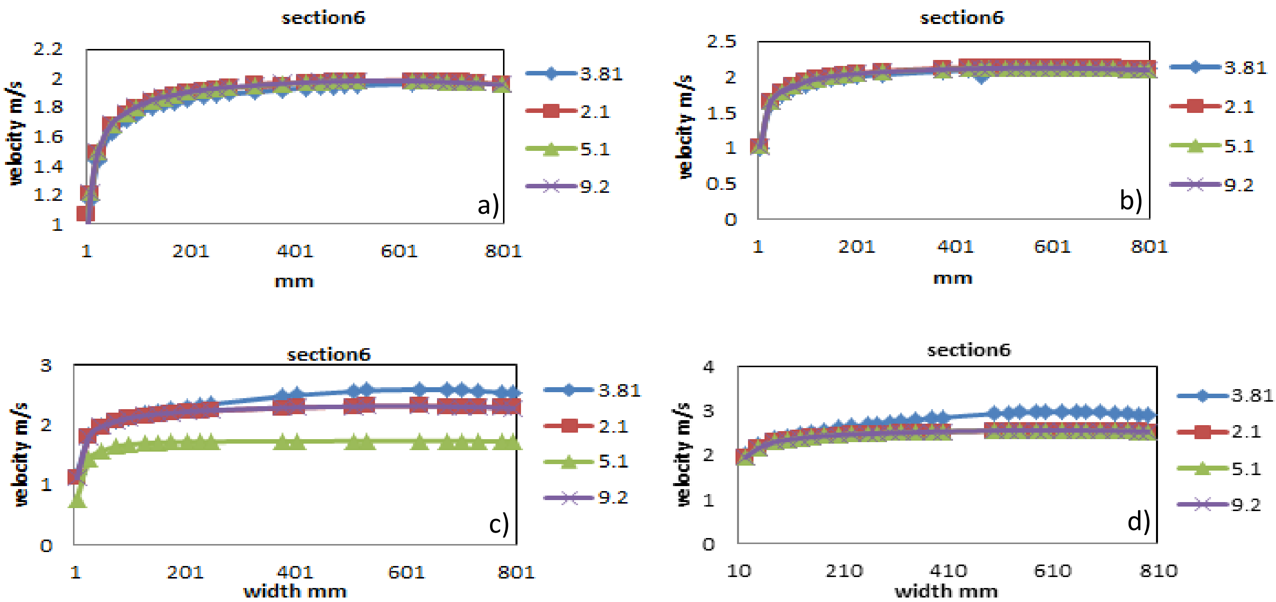


Fig 5.11 (a), (b), (c), (d) comparison of depth averaged velocity of section6 of the skewed portion with Q=16.2L/s,21.4L/s,29.6L/s,43.4L/s respectively

Graphs are plotted for the simulation results of CCHE-2D using DEM files of four different channels having flood plains skewed to 3.81°, 2.1°, 5.1° and 9.2° with respect to the main channel. From the above graphs it is clear that for 2.1° skewed angle the velocity values are high than the values from 3.81°, 5.1° and 9.2° skewed compound channels. The variation of velocity values between main channel and the flood plains is less, and there is a deviation in section 3 for 5.1° skewed channel as the values are more than the 3.81° skewed channel this may be due to the turbulence effect or effect of discharge in the channel. These velocity values obtained from CCHE-2D software are over estimated hence one cannot use this software efficiently.

CHAPTER 6

ENERGY LOSS CALCULATIONS AND ANN MODEL EQUATION

6.1 OVERVIEW

This chapter deals with the procedure of energy loss calculations and development of ANN model equation with trained weights and biases. Skewed region of the artificial channel was divided into five sections and the datum height (Z), water height (y) and velocity head ($\frac{\alpha V^2}{2g}$) are calculated at each and every five sections. These values are used to calculate energy loss at five sections in the skewed region using basic energy loss equation. By using Artificial Neural Network (ANN) all the input and output parameters are trained and tested for model equation. Four different model were tested with different input parameters among them model 4 resulted good co-relation coefficient and co-efficient of determination. Hence model 4 was taken as efficient model and the connection weights and biases for input and output parameters were taken and by using sigmoid transfer function model equation was developed. Sensitivity analysis was also done by using two different methods viz. Garson's algorithm and Connection weight approach method. Sensitivity analysis will be used to find out the important input parameter responsible for output parameter energy loss.

6.2 ENERGY LOSS CALCULATIONS

In order to predict energy loss in a compound channel having skewed flood plains first thing to be done is to observe the pattern of the energy loss in non-prismatic compound channel. This can be done by calculating energy values at each section in the skewed portion of the channel which is the study area in the channel. Then the energy loss between reference section and the required section is calculated and a graph has to be plotted between energy loss and relative distance or skewed portion. For calculating energy values along different sections the skewed portion of the channel is divided into five different sections and the starting point of the skewed region were taken as reference section.

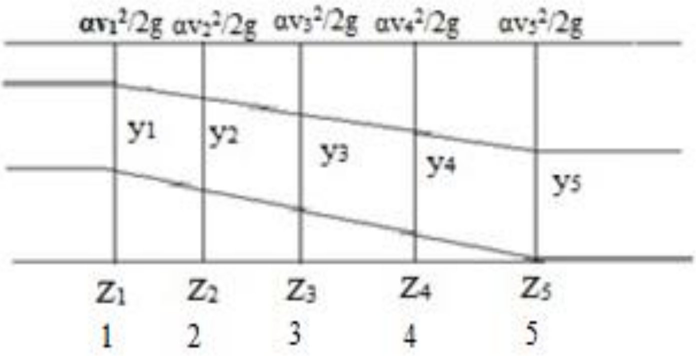


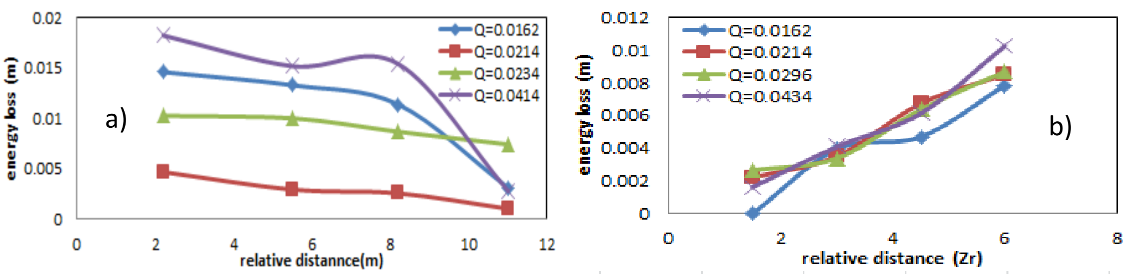
Fig 6.1 sketch of the sections in the skewed portion of the channel

From the fig 6.1 it is clear that the downstream region of the skewed portion of the channel i.e. section5 is taken as the datum level and the corresponding datum values of other sections are calculated using the longitudinal slope and the skewed distance between each section. And the datum values are represented by Z which gives datum head. The water surface levels at each section are taken and these values are represented by Y which gives the water surface level. The velocity head is calculated by taking the velocity values at each section represented by V. The total energy values at different sections and energy loss (h_l) between reference section and the remaining sections in the skewed portion are calculated by using formulae as listed below.

$$E = Z + Y + \frac{\propto V^2}{2\times 9.81} \tag{6.1}$$

$$E_1 - E_i = h_l \tag{6.2}$$

In the equation (6.2) E_i represents the energy values at section 2,3,4,5 respectively. Variation of energy loss along the skewed portion of the channel for different skew angles are shown in the plots as below.



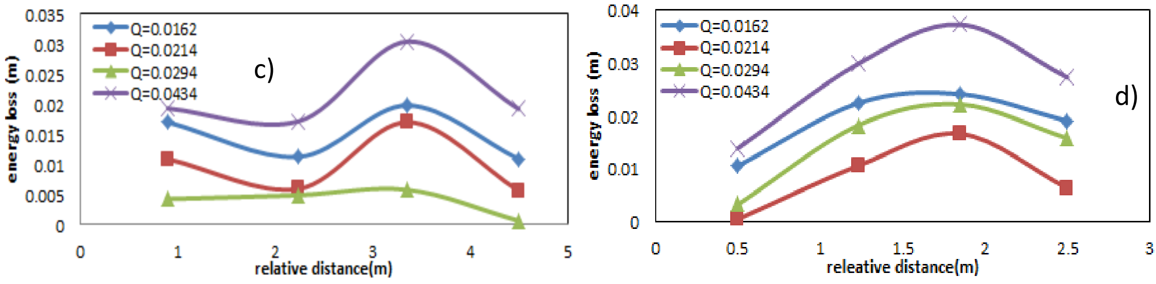


Fig 6.2 (a),(b),(c),(d) variation of energy loss along the skewed region of the channel for different skew angle like 2.1°, 3.81°, 5.1°, 9.2° respectively

From the fig 6.2 (a),(b),(c)and (d) it is clear that the energy loss increases as the skew angle increases and for the skew angle of 2.81° more energy loss takes place in the starting region of the skewed part and reaches minimum value of energy loss at the end of the skewed region but as the skew angle increases to 3.81°, 5.1° and 9.2° the maximum energy loss takes place near the end part of the skew region and the less energy loss takes place at the starting part of the skewed region which is exact opposite to the condition which happened in the case of 2.1° skew angle this may happens due to increase in the turbulence in the skewed region when the skew angle is increased.

6.3 PREDICTION OF ENERGY LOSS

Prediction the energy loss in a non-prismatic channel is somewhat difficult because energy loss depends on many hydraulic parameters and the flow phenomenon in non-prismatic channel is very complex which makes difficult in analysing the flow. Hence there is a need of some arbitrary method which develops a model for predicting energy loss in non-prismatic compound channel. For this purpose Artificial Neural Networks (ANN) is taken in order to develop a model for predicting energy loss. This method works on the principle that by using some influencing parameters it develops a relation between the input parameters and the output parameter. The relation develops depends upon the number of hidden neurons which are used while training data sets. ANN works on the weight age factors which gets assigned while training and validation of data sets. The accuracy of the model depends upon the extent that how much it is co related with the output parameter. In the present study the input parameters are some of the hydraulic parameters which include as follows:

1. Relative flow depth (β) = $\frac{H-h}{H}$, H= height of water in a particular section, h= height of main channel.
2. Skew angle (θ)
3. Width ratio (α) = $\frac{B}{b}$, B = width of flood plains, b = width of the main channel.
4. Aspect ratio of the main channel (σ) = $\frac{b}{h}$, b = width of the main channel, h= depth of main channel.
5. Relative distance (O_r) i.e. the total length of the skewed region in the channel.

The output parameter includes energy loss. This ANN tool is found in the commercial software MATLAB which helps in predicting the energy loss. This tool firsts trains the data which was given as input along with target output and then it validates the data sets and then it tests the data sets and finally gives a relation between input variables and the output parameter. For the present work 68 data sets were used, among these 68 data sets 55% were used for training purpose and 20% for validating purpose and the remaining 25% for testing purpose. Four different models were tested with different input parameters for each model. Feed-Forward Back propagation method is employed as the training function in ANN. As there was a belief that ANN is a black box model but actually it is not completely true because in ANN we can find out the physical effects of the variables on the output parameters. Physical effects on the output parameters can be figured out by taking connection weights and the biases of the models. For using this technique the data sets are normalised in a range between 1 and 0.

6.4 ANN MODEL EQUATION FOR ENERGY LOSS BASED ON TRAINED NEURAL NETWORK

By using ANN a model equation can be developed by using a sigmoid transfer function. There are four input variables hence we can use the basic equation for developing a model equation. The mathematical equation which unites the input and output variables can be written as below

$$\Delta E_n = f_{sig}\{b_0 + \sum_{k=1}^{h}[w_k * f_{sig}[b_{hk} + \sum_{i=1}^{m} w_{ik}\, X_i]]\} \tag{6.3}$$

Where ΔE_n is the normalized energy loss (in the range of 0 to 1 in this case),

b_0 = bias at the output layer,

W_k = connection weight between k^{th} neuron of hidden layer and single output neuron,

b_{hk} = bias at the k^{th} neuron of the hidden layer,

h = number of neurons in the hidden layer,

W_{ik} = connection weight between i^{th} input variable and k^{th} neuron of hidden layer,

X_i = normalized input variable "i" in the range [0 ,1],

f_{sig} = sigmoid transfer function

using the values of weights and biases in the table 6.1 the equation 6.3 can be simplified to the following equations to attain final co-relation of ΔE with the input variables

$$A_1 = -0.30407 - 0.41030\theta + 4.518\alpha - 4.8591Z_r \tag{6.4}$$

$$A_2 = 1.1311 + 1.37820\theta - 1.8631\alpha + 2.5879Z_r \tag{6.5}$$

$$A_3 = -6.6803 - 5.52520\theta - 0.94207\alpha + 0.22627Z_r \tag{6.6}$$

$$B_1 = 0.85479 \times \frac{e^{A_1} - e^{-A_1}}{e^{A_1} + e^{-A_1}} \tag{6.7}$$

$$B_2 = 0.56554 \times \frac{e^{A_2} - e^{-A_2}}{e^{A_2} + e^{-A_2}} \tag{6.8}$$

$$B_3 = 1.8956 \times \frac{e^{A_3} - e^{-A_3}}{e^{A_3} + e^{-A_3}} \tag{6.9}$$

$$C_1 = 1.0413 + B_1 + B_2 + B_3 \tag{6.10}$$

$$\Delta E_n = \frac{e^{C_1} - e^{-C_1}}{e^{C_1} + e^{-C_1}} \qquad (6.11)$$

The value of ΔE_n obtained from the equation 6.11 is in the range of [0, 1] which has to be de normalized using the following equation

$$\Delta E = 0.5[\Delta E_n + 1][\Delta E_{max} - \Delta E_{min}] + \Delta E_{min} \qquad (6.12)$$

Where ΔE_{max} and ΔE_{min} are the maximum and minimum values of ΔE in the data sets respectively.

6.5 SENSITIVITY ANALYSIS

Sensitivity analysis is to be carried out in order to find out the important input parameter that plays a major role in energy loss phenomenon. There are two methods which were used to carry out sensitivity analysis they Garson's algorithm and Connection weight approach method which were effectively used in the past research work. Sensitivity analysis was carried out for the model which has given good co-relation coefficient R i.e. model 4. Firstly Garson's algorithm was used to perform the sensitivity analysis and found that the most important input parameter which plays a major role in energy loss phenomenon was skew angle (θ) with 36.42% of importance and it is followed by relative distance (Z_r) with 33.142% of importance and width ratio (α) with 30.46% of importance in causing energy loss in the compound channel. Secondly connection weight approach method was used to perform sensitivity analysis. Outcome of this method was that the input parameter skew angle (θ) has S_i = 10.90231 followed by relative distance (Z_r) having S_i = -2.26103 and width ratio (α) having S_i = 1.101719. Ranking of the input parameters in this method has to be done based on the S_i value; skew angle (θ) is having highest S_i value among all the three input parameters taken hence it was given rank 1 followed by relative distance with second highest S_i value and given as rank 2 lastly the width ratio (α) with the least S_i value was given rank 3. Negative and positive signs give information about the relationship of input parameters with the output parameters. From the above result input parameters relative distance (Z_r) is inversely related to the output parameter energy loss but the input parameters skew angle (θ) and width ratio (α) are directly related to the output parameter energy loss.

6.6 GARSON'S ALGORITHM

This Garson's Algorithm was used in performing the sensitivity analysis through which it is possible to know the most important parameter influencing the output parameter. In this algorithm absolute values are taken into consideration and are used to calculate the relative importance of input variables. But this method does not give information whether the input parameter is directly or indirectly related to the output parameter.

The equation which was used in Garson's Algorithm is as below:

$$\text{input}_X = \frac{\sum_{y=1}^{3}|Hidden_{XY}|}{\sum_{Z=1}^{3}|Hidden_{ZY}|} \qquad (6.13)$$

y = number of hidden layers,

Z = number of input variables, X= 1, 2, 3

6.7 PRODUCT MATRIX FOR GARSON'S ALGORITHM

$$\begin{bmatrix} 0.351 & 3.85664 & 4.15351 \\ 0.77943 & 1.05366 & 1.4636 \\ 10.4736 & 1.7858 & 0.42892 \end{bmatrix} \begin{matrix} \sum 8.3615\,0 \\ \sum 3.29669 \\ \sum 12.68832 \end{matrix}$$

Elements in the product matrix are obtained by multiplying the output parameter weights in the table 6.2 with the input parameter weights in the same table. The entire elements in the product matrix are added along row wise. Each element in the particular row of the production matrix is divided by the respective sum of all elements in that particular row and the matrix obtained is as follows:

$$\begin{bmatrix} 0.042 & 0.4613 & 0.497 \\ 0.23643 & 0.32 & 0.444 \\ 0.82545 & 0.141 & 0.0034 \end{bmatrix}$$

$$S_1 = \sum 1.10388 \quad S_2 = \sum 0.9223 \quad S_3 = \sum 1.0044$$

Sigma values obtained are S_i values for each column of the above matrix. Now these sigma values are added i.e. $S_1 + S_2 + S_3$. Relative importance of input parameters are calculated for each input value as follows;

Relative importance of input 1 = $\frac{S_1}{S_1+S_2+S_3}$ (6.14)

Relative importance of input 2 = $\frac{S_2}{S_1+S_2+S_3}$ (6.15)

Relative importance of input 3 = $\frac{S_3}{S_1+S_2+S_3}$ (6.16)

Relative importance of each input parameter in percentage value was listed in table 6.3.

6.8 CONNECTION WEIGHT APPROACH METHOD

This was another method which was used to perform sensitivity analysis among the input parameters. This method is different from the Garson's algorithm that this method gives the information regarding whether the input parameter is directly or indirectly related to the output parameter. Input parameter is directly related to the output parameter when the S_i value of the input parameter is positive and the input parameter is indirectly related to the output parameter when the S_i value of the input parameter is positive.

Equation which was used in connection weight approach method is as follows:

$$\text{input}_X = \sum_{y=1}^{3} Hidden_{XY} \quad (6.17)$$

Y= number of hidden layers

Z= number of input parameters, X= 1, 2, 3

6.9 PRODUCT MATRIX FOR CONNECTION WEIGHT APPROACH METHOD

$$\begin{bmatrix} -0.35072 & 0.77943 & 10.4736 \\ 3.85664 & -1.05366 & -1.78579 \\ -4.153510 & 1.463561 & 0.42892 \end{bmatrix} \begin{matrix} S_1 = \sum 10.90231 \\ S_2 = \sum 1.101719 \\ S_3 = \sum -2.26103 \end{matrix}$$

Elements in the product matrix are obtained by multiplying output parameter weight of a particular hidden layer with the input parameter weight of that respective hidden layer in the table 6.2. All the elements in the product matrix are added along row wise hence for each row there will be one sum of all elements of that particular row. The values obtained are S_i values. Ranking of the parameters are done based on the S_i value and it was given in table 6.4.

TABLE 6.1 Different ANN models and their statistical performances

MODELS	INPUTS	Coefficient of Co-relation(R)		Coefficient of efficiency (R^2)	
		Training	Testing	Training	Testing
MODEL 1	H_r , Z_r θ, α,	0.7252	0.8375	0.5360	0.7014
MODEL 2	H_r , Z_r θ,	0.5250	0.6500	0.2756	0.4225
MODEL 3	Z_r , θ,	0.7642	0.6957	0.5840	0.4840
MODEL 4	θ, α, Z_r	0.8000	0.8264	0.6400	0.6830

From table 6.1 it was clear that among all the four different models, model 4 with the input parameters skew angle (θ) , width ratio (α) and relative distance (Z_r) is having high coefficient of co-relation (R) and coefficient of efficiency (R^2). Hence model 4 is considered as the best model for developing ANN model equation.

TABLE 6.2 Connection weights and biases

Neuron	Weights (W_{ik})				Biases	
	Input 1	Input 2	Input 3	Output	b_{hk}	b_o
Hidden Neuron 1 (k=1)	-0.4103	4.518	-4.8591	0.85479	-0.30407	1.0413
Hidden Neuron 2 (k=2)	1.3782	-1.8631	2.5879	0.56554	1.1311	_
Hidden Neuron 3 (k=3)	5.5252	-0.94207	0.22627	1.8956	-6.6803	_

Table 6.2 contains values of ANN trained weights and biases. In the above table for every hidden neuron there are weight values for three input parameters and one output parameters and also bias value for that particular hidden neuron. From the table it was clear that there will be only one output bias b_o because there is only one output layer or output parameter.

TABLE 6.3 Relative importance of different inputs as per Garson's algorithm

Parameters	Relative importance (%)	Ranking of inputs as per relative importance
Skew angle (θ)	36.42	1
Width ratio (α)	30.46	3
Relative distance (Z_r)	33.142	2

From the table 6.3 it was clear that the input parameter skew angle (θ) is having an importance of 36.42% which was considered as a most influencing parameter for energy loss and it was given 1st rank. Relative distance (Z_r) has relative importance of 33.142% which was considered as second most important parameter influencing energy loss and was given 2nd rank. Width ratio (α) has relative importance of 30.46% which was considered as third important parameter influencing energy loss and was given rank 3. This table was prepared based on Garson's algorithm.

TABLE 6.4 Ranking of input parameters as per Connection weight approach method

Parameters	S_i value	Ranking of inputs as per S_i value
Skew angle (θ)	10.90231	1
Width ratio (α)	1.101719	3
Relative distance (Z_r)	-2.26103	2

From table 6.4 skew angle (θ) is having highest S_i value of 10.90231 hence it was considered as an most important input parameter and it was given rank 1. Relative distance is having S_i value of -2.26103 which was second to the skew angle so it was considered as a second most important parameter for energy loss. Negative sign indicates that the relative distance is inversely proportional to the energy loss. Width ratio (α) is having value of S_i = 1.101719 which was least among all the variables hence it was given rank 3. This table was prepared based on connected weight approach method.

CHAPTER 7

CONCLUSIONS

7.1 CONCLUSIONS

Prediction of energy loss in a compound channel having skewed flood plains was carried out in the present work. Conclusions from the work are as follows:

1. Energy loss in compound channel having skewed flood plains depends on different hydraulic parameters like width ratio (α), skew angle (θ), relative distance (Z_r), aspect ratio (σ) and effective height (β).
2. Among all the four models developed 4^{th} model with input parameters width ratio, skew angle and relative distance and output parameter as energy loss was the best with co-relation coefficient R=0.80 for training and R= 0.82642 for testing.
3. Using sigmoid transfer function along with connection weight factors and biases an ANN equation has modeled.
4. By sensitivity analysis it was inferred that skew angle (θ) is the most important factor for causing energy loss in a skewed compound channel.
5. From the connection weight approach method physical effects of the input parameters on the output parameter energy loss was studied and was found that the skew angle (θ) and width ratio (α) are directly related to the energy loss i.e. with the increase in these two parameters there will be increase in the energy loss.
6. Relative distance (Z_r) was found to be inversely related to the energy loss i.e. with the increase in relative distance there will be decrease in energy loss.
7. Software Computational Centre for Hydro-science Engineering (CCHE-2D) was over estimating the velocity values and boundary shear stress values when compared with experimental results.
8. Basic methods for calculating discharge values in an artificial channel can be effectively used in skewed compound channel also because these methods are in good relation with the experimental values.

7.2 SCOPE FOR FUTURE WORK

There is a lot of scope for the work to be done in future in this study area i.e. energy loss in a compound channels having skewed flood plains. Future scope for the present work was summarized as below:

- Effect of number of hidden layers and hidden neurons in developing the ANN model equation based on trained weights has to be studied.
- Regarding any technique that minimizes the error among the connected weights and biases of the trained ANN network has to be studied.
- Effect of different training functions and learning functions on the trained ANN network has to be studied because in the present study only one training function Feed- Forward Back Propagation network has used.

REFERENCES

[1] B. Naik, Kamel Miri & K.K. Khatua " Prediction of energy loss along non prismatic reach of a compound channel using ANN", *River flow 2014,Talor & Francis group, ISBN978-1-138-02674-2* (2014)

[2] Bousmar, D., "Flow modelling in compound channels - Momentum transfer between main channel and prismatic or non-prismatic floodplains". *PhD Thesis, Universite Catholique de Louvain*, Belgium 2002

[3] Bousmar, D., and Zech, Y., "Momentum transfer for practical flow computation in compound channel" *J. Hydraulic. Eng., 125*(7), 696-706. 1999

[4] Bousmar, D., Proust, S. & Zech, Y. "Experiments on the flow in a enlarging compound channel", *Proc. River Flow 2006 Conference, Lisbon, Portugal, 1, 323-332.* (2006)

[5] Bousmar, D., Wilkin, N., Jacquemart, J.H., Zech, Y., "Overbank flow in symmetrically narrowing floodplains." *J. Hydraul. Eng., ASCE, 130(4), 305-312* (2004)

[6] C.McGahey, and P. G. Samuels. "Methodology for conveyance estimation in two-stage straight, skewed and meandering channels." *Proceedings of the XXX congress of the international association for hydraulic research*. Vol. 1. 2003.

[7] Center for Computational Hydroscience Engineering Mesh (CCHE-2D) User's Manual.

[8] Center for Computational Hydroscience Engineering User's Guide. (CCHE-2D).

[9] Chlebek, J. "Modelling of simple prismatic channels with varying roughness using the SKM and a study of flows in smooth non-prismatic channels with skewed floodplains." Diss. University of Birmingham, 2009.

[10] Chlebek, J., D. Bousmar, D. W. Knight, and M. Sterling. "A comparison of overbank flow conditions in skewed and converging/diverging channels." In*Riverflow 2010, Proceedings of the international conference on fluvial hydraulics*, vol. 1, pp. 503-511. 2010.

[11] D.S.Kumar, and P.K Basudhar. "Prediction of residual friction angle of clays using artificial neural network." *Engineering Geology*100.3 (2008): 142-145.

[12] Das B.S, K.K.Khatua, K.Devi "Analysis of flow in skewed and converging compound channel", *International Journal on Recent and Innovation Trends in Computing and Communication Vol -3 issue -2 (2014) ISSN 2321-8169(136-140)*

[13] Elliott, S. C. A., and R. H. J. Sellin. "SERC flood channel facility: skewed flow experiments." *Journal of Hydraulic Research* 28.2 (1990): 197-214.

[14] Elliott, S. C.A. "An investigation into skew channel flow", *PhD Thesis, The University of Bristol*, January (1990)

[15] Ikeda, S. and Kuga, T., "Laboratory study on large horizontal vortices in compound open channel flow", *Journal of Hydraulic, Coastal and Environmental Engineering, JSCE, Vol. 45, pp 493- 498* (1997)

[16] J.H. Kadhem. "Flow in two-stage channels with the main channel skewed to the flood plain direction*". Diss. University of Glasgow*, 1990.

[17] James, Maurice, and Bobby J. Brown. "Geometric parameters that influence floodplain flow*". No. WES-RR-H-77-1. Army Engineer Waterways Experiment Station Vicksburg Miss*, 1977.

[18] K.C Patra and K. K. Khatua. "Energy loss in two stage meandering and straight compound channels." (2005).

[19] K.K. Khatua "Interaction of flow and estimation of discharge in two stage meandering compound channels". Diss. 2007.

[20] Khatua K.K and Patra K.C "Apparent shear stress and boundary shear distribution in a compound channel flow" *Computational Methods and Experimental Measurements XV, WIT eLibrary, pp. 215-228, volume 51 of WIT Transactions on Modelling and Simulation (ISSN 1743-355X)*, 2011

[21] Khatua K.K, Patra K.C, and Mohanty P.K."Stage-Discharge Prediction for Straight and Smooth Compound Channels with Wide Floodplains'' *J. Hydr. Engg., ASCE* (2012)

[22] Kiely, G.K., and McKeogh, E.J., "Secondary current rotations during flood flow in meandering channels", *Advances in Hydro-Science and Engineering*, Vol. 1, pp.1215-1225 (1993)

[23] Knight, D. W., & Hamed, M. E. "Boundary shear in symmetrical compound channels". *Journal of Hydraulic Engineering* ,(1984)

[24] Knight, D. W., &, J. D. Demetriou, "Flood Plain And Main Channel Flow Interaction". *Journal Of Hydraulic Engineering*, *109*(8), 1073-1092 (1983)

[25] Knight, Donald W., and J D. Demetriou. "Flood plain and main channel flow interaction." *Journal of Hydraulic Engineering* 109.8 : 1073-1092 (1983)

[26] Naik, B., and K. K. Khatua. "Water Surface Profile Computation in non-prismatic Compound Channels." *Aquatic Procedia* 4 (2015): 1500-1507.

[27] Omran, M.N., 2005, Modelling stage-discharge curves, velocity and boundary shear stress distributions in natural and artificial channels using a depth averaged model, PhD Thesis, The University of Birmingham

[28] Proust S, Bousmar D, Rivière N, Paquier A, Zech Y. "Energy losses in compound open channels. Advances in water Resources". 2010 Jan 31

[29] Proust, S., Rivière, N., Bousmar, D., Paquier, A., Zech, Y. & Morel, R. "Flow in compound channel with abrupt floodplain contraction", *J. Hydr. Eng., ASCE*, 132(9), 958-970. (2006)

[30] Mohanty, P. K. "Flow Analysis of Compound Channels With Wide Flood Plains" *PhD diss*., 2013.

[31] Rezaei, B. "Overbank flow in compound channels with prismatic and non-prismatic floodplains." *PhD Thesis, Univ. of Birmingham*, U.K.(2006)